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Evaluation of Fertilizer Additives for Enhanced Nitrogen Efficiency in Corn

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Abstract
The use of N additives and slow release materials with ammoniacal fertilizer varies throughout the U.S. Corn Belt due to differing N loss potentials across climate, soils, and production systems. In Iowa, recent years of high rainfall events and prolonged wet soil conditions has renewed interest to protect fertilizer N loss from denitrification, leaching, and greenhouse gas emission with use of nitrification inhibitors. These loss processes can be significant in Iowa soils that are poorly drained and have high organic matter, high pH, and high populations of denitrifying bacteria. Subsurface tile drainage is also prevalent in farmer fields throughout the state, a contributing pathway for nitrate leaching. Leaching loss is the major contributor to N in surfaces waters reaching the Gulf of Mexico. Farmers who utilize minimum or no-tillage systems can benefit from urease inhibitors to minimize volatilization from surface applied urea or urea containing fertilizers. Evaluation of urease and nitrification inhibitors, and slow release fertilizer products, is needed to best provide advice to farmers on appropriate use with urea fertilizers for agronomic performance, as well as potential to aid in reducing loss that affects water and air quality. Urea is an important N fertilizer source across the Corn Belt, with consumption in Iowa at approximately 180,500 U.S. tons (2010-2011 fertilizer year). Proper and improved use efficiency options are important for farmers.

The objective of the study was to determine the effect of urease inhibitors, nitrification inhibitors, and slow release urea products on soil inorganic-N, N use efficiency and yield in corn biomass and grain, and nitrous oxide (N2O) emission from soil.

Disciplines
Agricultural Science | Agriculture | Agronomy and Crop Sciences | Soil Science

Evaluation of Fertilizer Additives for Enhanced Nitrogen Efficiency in Corn

Final Project Report
(2013 and 2014)

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The use of nitrogen (N) additives and slow release materials with ammoniacal fertilizer varies throughout the U.S. Corn Belt due to differing N loss potentials across climate, soils, and production systems. In Iowa, recent years of high rainfall events and prolonged wet soil conditions has renewed interest to protect fertilizer N loss from denitrification, leaching, and greenhouse gas emission with use of nitrification inhibitors. These loss processes can be significant in Iowa soils that are poorly drained, and have high organic matter, high pH, and high populations of denitrifying bacteria. Subsurface tile drainage is prevalent in crop production fields throughout the state, a contributing pathway for nitrate leaching, with leaching loss the major contributor to N in surfaces waters flowing to the Gulf of Mexico. Farmers who utilize minimum or no-tillage systems can benefit from urease inhibitors to minimize volatilization from surface applied urea or urea containing fertilizers. Evaluation of urease and nitrification inhibitors, and slow release fertilizer products, is needed to best provide advice to farmers on appropriate use with urea fertilizer for agronomic performance, as well as potential to aid in reducing loss that affects water and air quality. Urea is an important N fertilizer source across the Corn Belt, with consumption in Iowa at approximately 195,000 U.S. tons urea (2012-2013 fertilizer year). Proper and improved use efficiency options are important for farmers.

The objective of the study was to determine the effect of urease inhibitors, nitrification inhibitors, and slow release urea products on soil inorganic-N, corn plant N use efficiency, grain yield, and nitrous oxide (N_2O) emission from soil.

Materials and Methods

A field trial was conducted at two ISU Research and Demonstration Farms (Ag Engineering and Agronomy Farm near Ames and Northern Research and Demonstration Farm near Kanawha) in 2013 and 2014. The soils at Ames were Canisteo silty clay loam/Webster clay loam/Clarion loam. The soil at Kanawha was Canisteo clay loam. Sites were selected for higher probability of response to product application, that is a landscape position with fine textured, poorly drained, and high organic matter soils (Table 1). The prior-year crop at each site was soybean. At Ames in 2013, 138 lb/acre of MES (13-33-0-15S, MicroEssentials) was surface broadcast applied to the study area in fall 2012. At that site in 2013, a field cultivator was used in the spring to incorporate fall applied fertilizer and pre-emergence herbicide prior to N treatment application. At all other sites, no tillage was performed in fall and spring prior to N treatment application.

Products evaluated are listed in Table 2 and supplied from Koch Agronomic Services (Agrotain and SuperU), Dow AgroSciences (Instinct), Agrium Advanced Technologies (ESN), and Rosen's Inc. (Factor). The urea treated with Agrotain, Instinct, and Factor were impregnated using a bench top mixer. Granular diatomite was added as a drying agent to reduce urea wetness.

SuperU and ESN were supplied with integrated inhibitor products in urea or coated urea. Timing of urea application occurred when spring soil temperatures were above 50 degrees F and fit for tillage prior to corn planting. All urea and treated urea products were broadcast applied by hand. Incorporated treatments were surface broadcast and mixed to a shallow 0-6 inch depth into the soil with a field cultivator (control of volatilization). The no incorporation treatments were surface broadcast without incorporation (no control of volatilization). All treatments for each site were applied the same day. The study was a randomized complete block design with four replications.

Soil samples were collected at the 0-6 inch depth in the spring prior to treatment application and spring tillage and analyzed for soil test P (STP), soil test K (STK), pH, and organic matter; and at a 0-1 and 1-2 foot depth for NH_4-N and NO_3-N. Soil was collected in June approximately 30 days after N application and analyzed for NH_4-N and NO_3-N at the 0-1 and 1-2 foot depths. Corn N stress was estimated using a Holland Scientific Crop Circle active canopy sensor at the V10-V12 corn growth stage. The chlorophyll index (Chl) was calculated using visible and near infrared canopy reflectance. At physiological maturity (R6), aboveground corn biomass samples were collected by hand from each treatment. Total N was determined for corn vegetation, grain, and cob (total plant N uptake). Two nitrogen use efficiency indices were calculated, recovery efficiency of applied N (RE) and productivity efficiency (PRE). The RE index is total plant N uptake with N applied for each treatment minus total plant N uptake with no N applied divided by the applied N rate of 120 lb N/acre. The PRE index is total plant N divided by grain yield at 15.5% moisture. Grain was harvested using plot combine equipment and yield was adjusted to 15.5% moisture content.

At the Ames site in 2013, N_2O emissions from the soil surface were measured in the incorporated treatments on ten measurement dates from pre-fertilizer application through October. In each plot, a metal frame (30 inches long x 15 inches wide x 4 inches in height) was inserted approximately 3 inches into the soil. On each measurement date, a chamber (30 inches long x 15 inches wide x 4 inches in height) was placed over the metal frame and sealed. During a 30-minute chamber closure, chamber gas was sampled every 10 minutes (including time zero) through a septum with a syringe. Samples were injected into vacuumed vials and analyzed for N_2O concentration with gas chromatography. The concentration of N_2O was converted to a mass of N_2O-N, and the flux of N_2O-N over time was best fit and calculated with a linear model.

Results

The Ames site in 2013 experienced extensive wet, cool soil conditions just after corn planting. The resulting wet soils for an extended period damaged seedling growth and severely reduced corn stand. Therefore, the V10 sensing measurements, R6 corn biomass (RE and PRE indices), and grain yield could not be collected.

Soil NO_3-N and NH_4-N concentrations were determined from soil collected in June. In Table 3, all N applications had a higher NO_3-N concentration than the no-N control in both the 0-1 and 1-2 foot depths. There were no significant main effect differences for NO_3-N concentration with any product treatment at the 0-1 foot depth. There was a main effect of product treatment with soil NO_3-N concentration in the 1-2 foot depth. Factor had significantly greater NO_3-N concentration than other treatments, and ESN had lower concentration than untreated urea. Other products were not different from the untreated urea or from other products. The NO_3-N concentrations in the 1-2 foot depth with all treatments were greater than the untreated no-N control, indicating downward movement of NO_3-N in the soil profile, even with inhibitor and slow-release products. Soil NH_4-N concentrations (Table 4) had a significant mean product effect in the top foot. The ESN and SuperU products had the greatest NH_4-N concentrations, however, differences were small. In the 0-1 foot depth, the untreated control was statistically different than urea treatments (with no incorporation and mean across incorporation or no incorporation). The NH_4-N concentration for all urea product treatments was not different than the untreated control in the 1-2 foot depth. For both sample depths, NH_4-N concentrations were low and near the concentrations for the no-N control, indicating near complete nitrification of applied urea. With the coated ESN material, there could have been N still inside granules, but if present, that may or may not have been released and detected during soil extraction.

Nitrogen stress measurement (Chl index) with canopy sensing was not different for any product application, incorporation, or interaction (Table 5). The Chl index was increased with applied urea product treatments in all cases (compared to the zero N control), indicating corn plant response to applied N at the mid-vegetative growth stage. However, there was no corn canopy difference due to product application or incorporation at that mid-vegetative growth period.

Corn grain yield was increased with all urea product applications (treated or untreated) (Table 5). The yield response indicates all sites were N responsive. Fertilizer N rate trials (applied N and corn planting date the same day as the product trials) were conducted adjacent to each site, with an overall agronomic optimum N rate at 172 lb N/acre and a yield at the agronomic optimum of 185 bu/acre (Table 6). The overall optimum N rate indicates that the 120 lb N/acre rate used in the product evaluation should have allowed potential N losses (volatilization or leaching) to be reflected in reduced yield. That is, the 120 lb N/acre rate was below agronomic optimum and any N losses should have influenced N response and yield. No urease or nitrification product, incorporated or surface applied, resulted in yield higher than untreated urea. Moreover, a significant yield difference between products was found due to a yield reduction with Instinct (no incorporation) and Factor (incorporated). It is unknown why the products at those placements would result in lower yield.

Nitrogen use efficiency calculated using the RE and PRE indices showed no significant main (incorporation and product) or interaction effects (incorporation x product) (Table 7). The PRE was significantly less for zero N compared to all urea treatments. However, there were no significant incorporation or urea product effects.

There were significant rainfall events after product application at both the Ames and Kanawha sites each year (Figs. 1 and 2). The period between N application and soil sample collection (at the 0-1 and 1-2 foot depths) had total rainfall amounts of 9.3 inches at Ames and 15 inches at Kanawha during 2013, and 7.9 inches at Ames and 9.4 inches at Kanawha during 2014. This would potentially result in conditions favorable for NO_3-N loss by leaching or denitrification. However, either loss did not take place or the nitrification inhibitors/polymer-coated urea was not effective in keeping more NH_4-N and less NO_3-N present during the wet conditions. Little to no volatilization likely occurred as indicated by the rainfall events soon after application and as indicated by the inorganic-N concentrations.

Nitrous oxide emissions varied across measurement dates and fertilizer N products applied at Ames (Fig. 3) in 2013. The highest N_2O emissions occurred 5 days after N application. Untreated urea, Agrotain, and SuperU had the greatest emissions on that date, whereas, the lowest emissions were from urea treated with Instinct and ESN. On June 7, the no N control and product treated urea (Agrotain, SuperU, Instinct, and ESN) had similar emission, with urea notably producing greater N_2O emission. However, measurements were highly variable across replications, resulting in no statistical differences on that date. There was a treatment effect on June 20, with Instinct and Agrotain having higher emission than other treatments. In the early growing season, untreated urea had the highest N_2O emissions, with a variable decrease in emissions with the inhibitor products. Polymer-coated urea (ESN) had the most consistent effect on decreasing N_2O emission. In the early season time frame, between the period from just after N application to July 1 (highest N_2O emission timeframe), treatment differences were observed only 2 out of the 5 sample dates.

Summary

In this study, no agronomic benefits were found when using urea with nitrification inhibitors (Instinct, SuperU), urea with urease inhibitors (Agrotain, SuperU, Factor), or urea with a polymer coating (ESN). Sites were selected with landscape positions that could promote significant denitrification (fine textured, poorly drained, and high organic matter soils), and a treatment designed to enhance potential volatilization (no incorporation). Responses to inhibitor products were likely due to several factors. Rainfall timing and amount shortly after application should have moved surface applied uncoated urea into the soil profile before there was significant hydrolysis of urea or volatilization of NH_3. Also, there would be greater soil retention of NH_4 with high soil CEC and row cleaners covering some surface applied urea during corn planting. Conversion of NH_4 to NO_3 (nitrification) could have been slowed from cool soil temperatures after application, mirroring the effects of nitrification inhibitor products. However, soil NH_4-N concentrations did not reflect any slowing of nitrification from the nitrification inhibitors. In early May 2013, a significant snowfall event occurred at both sites, indicating cold early season conditions that year. During most of June 2014, there were consistent rainfall events keeping soils wet, which should have promoted denitrification and leaching. If the nitrification inhibitor products or polymer-coated urea were not effective (or only partial effective) at reducing nitrification rate, then loss reduction in those wet conditions would not have occurred. This appeared to be the case as the profile soil NO_3-N concentrations in June were not different from the untreated urea. Soil N mineralization in high organic matter soils may have been higher than normal for much of the 2014 growing season, and could offset losses of applied N. Conversely, if nitrification inhibitors or urea coating were not effective at reducing NO_3-N buildup before periods of potential N loss, then there would not be an expected difference compared to untreated urea. This would be the case for urease inhibitors, as they are not designed to affect nitrification. Overall, soil NO_3-N concentrations were not high (below 20 ppm) in the 0-1 foot depth, which could indicate either slow nitrification, downward movement in the soil profile, or continued N loss conditions. The concentrations were elevated in the second foot compared to the no-N control, indicating downward movement. The N_2O emissions showed no more than 0.5 lb N_20-N/acre/day as measured at the Ames site in 2013 (Fig. 3). Nitrous oxide is an important greenhouse gas but typically represents only a small fraction of total N losses through denitrification.

Acknowledgements

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Table 1. Routine soil tests and inorganic-N concentration at each site, 2013 and 2014.

	Routine Soil Tests							
	0-6 inch				NH_4-N		NO_3-N	
Site	STP	STK	pH	OM	0-1 ft	1-2 ft	0-1 ft	1-2 ft
	--- ppm ---			%	----------------- ppm ---------------			
Ames 2013	H	O	7.2	7.3	3	2	2	5
Kanawha 2013	O	H	6.4	6.0	4	2	1	3
Ames 2014	H	VH	6.3	3.5	6	2	5	5
Kanawha 2014	H	H	5.9	5.6	4	1	5	5

Samples were collected in spring prior to corn planting.

Table 2. Nitrogen fertilizer, nitrification inhibitors, urease inhibitors, and slow release N products studied in 2013 and 2014. Each treatment was incorporated and unincorporated.

Treatment description	N rate
	lb N/acre
Zero N control	0
Urea	120
Urea treated w/ Agrotain Ultra (urease inhibitor - NBPT)†	120
SuperU (urea with urease and nitrification inhibitor - NBPT + dicyandiamide)‡	120
Urea treated w/ Instinct (nitrification inhibitor - nitrapyrin)§	120
Urea treated w/ Factor (urease inhibitor - NBPT + propriety solvent)¶	120
ESN (urea with polymer coating)	120

† Agrotain Ultra 20% product rate was 3 qt/ton (1.415 ml/lb urea).
‡ SuperU pretreated by manufacturer with inhibitors.
§ Instinct product rate was 35 fl oz/acre.
¶ Factor product rate was 3 qt/ton (1.415 ml/lb urea).

Table 3. Effect of N fertilizer, nitrification inhibitors, urease inhibitors, and slow release N products on soil NO_3-N concentration in June, 2013 and 2014.

		0-1 ft			1-2 ft		
Product	N Rate	Inc	No Inc	Mean	Inc	No Inc	Mean
	lb N/ac	----------------------------			NO_3-N (ppm)	----------------------------	
None	0	4†	3†	4†	5†	4†	4†
Urea	120	15	18	16	11	12	11b
Agrotain	120	16	18	17	9	10	10b
SuperU	120	17	18	17	10	10	10bc
Instinct	120	20	15	18	10	9	10bc
Factor	120	14	19	16	12	15	13a
ESN	120	20	21	21	8	8	8c
Mean		17	18		10	11	
				Statistics (P>F)‡			
Incorporation (Inc)			0.265			0.174	
Product (Prod)			0.364			<0.001	
Inc x Prod			0.287			0.454	

† Zero N statistically different than all urea treatments at P≤0.10.
‡ Statistical analysis not including the zero N control. Letters indicate significant differences at the P≤0.10 level.

Table 4. Effect of N fertilizer, nitrification inhibitors, urease inhibitors, and slow release N products on soil NH_4-N concentration in June, 2013 and 2014.

		0-1 ft			1-2 ft		
Product	N Rate	Inc	No Inc	Mean	Inc	No Inc	Mean
	lb N/ac	----------------------------			NH_4-N (ppm)	----------------------------	
None	0	4	4†	4†	2	2	2
Urea	120	5	5	5bc	3	2	3
Agrotain	120	4	5	5c	2	2	2
SuperU	120	6	6	6ab	3	3	3
Instinct	120	5	5	5bc	3	2	2
Factor	120	4	5	4c	2	3	3
ESN	120	6	7	6a	3	3	3
Mean		5	5		3	2	
				Statistics (P>F)†			
Incorporation (Inc)			0.283			0.789	
Product (Prod)			0.007			0.403	
Inc x Prod			0.976			0.126	

† Zero N statistically different than all urea treatments at P≤0.10.
‡ Statistical analysis not including the zero N control. Letters indicate significant differences at the P≤0.10 level.

Table 5. Effect of N fertilizer, nitrification inhibitors, urease inhibitors, and slow release N products on V10 corn canopy vegetative sensing (Chl) and grain yield, 2013 and 2014.

Product	N Rate	Vegetative Sensing Index Inc	No Inc	Mean	Grain Yield Inc	No Inc	Mean
	lb N/ac	------------- Chl -------------			------------ bu/acre ------------		
None	0	3.0†	3.2†	3.1†	95†	95†	95†
Urea	120	4.4	4.4	4.4	171	170	171a
Agrotain	120	4.5	4.6	4.6	164	170	167ab
SuperU	120	4.5	4.5	4.5	169	172	170a
Instinct	120	4.4	4.3	4.4	167	156	161b
Factor	120	4.3	4.7	4.5	156	168	162b
ESN	120	4.7	4.7	4.7	174	169	171a
Mean		4.5	4.5		167	168	
			Statistics (P>F)‡				
Incorporation (Inc)			0.287			0.769	
Product (Prod)			0.159			0.075	
Inc x Prod			0.464			0.110	

† Zero N statistically different than all urea treatments at $P \leq 0.10$.
‡ Statistical analysis not including the zero N control. Letters indicate significant differences at the $P \leq 0.10$ level.

Table 6. Corn yield response to N fertilizer rates from N rate trials adjacent to the study areas, 2013 and 2014.

Site	Model	P>F	R^2	Regression Parameters a	b	c	Plat. N	Plat. Yield
							lb N/ac	bu/ac
Ames 2013	QP	0.01	0.99	104.3	0.8665	-0.00206	210	195
Kanawha 2013	QP	0.001	0.99	104.8	1.2282	-0.00410	150	197
Ames 2014	QP	0.04	0.96	140.6	1.1554	-0.00603	96	196
Kanawha 2014	QP	0.05	0.95	78.5	0.7730	-0.00207	187	151
Mean	QP	0.001	0.99	108.1	0.8874	-0.00258	172	185

Table 7. Effect of N fertilizer, nitrification inhibitors, urease inhibitors, and slow release N products on nitrogen use efficiency, 2013 and 2014.

Product	N Rate	Recovery Efficiency of Applied N (RE)			Productivity Efficiency (PRE)		
		Inc	No Inc	Mean	Inc	No Inc	Mean
	lb N/ac	--------- Δlb N/lb N ---------			------------ lb N/bu ------------		
None	0	--	--	--	0.63†	0.64†	0.64†
Urea	120	0.58	0.60	0.59	0.77	0.78	0.78
Agrotain	120	0.54	0.57	0.55	0.76	0.76	0.76
SuperU	120	0.67	0.58	0.62	0.83	0.76	0.80
Instinct	120	0.60	0.50	0.55	0.79	0.78	0.79
Factor	120	0.52	0.63	0.58	0.78	0.81	0.80
ESN	120	0.63	0.57	0.60	0.78	0.77	0.77
Mean		0.59	0.58		0.79	0.78	
				Statistics (P>F)‡			
Incorporation (Inc)			0.576			0.351	
Product (Prod)			0.556			0.293	
Inc x Prod			0.159			0.102	

† Zero N statistically different than all urea treatments at P≤0.10.

‡ Statistical analysis not including the zero N control.

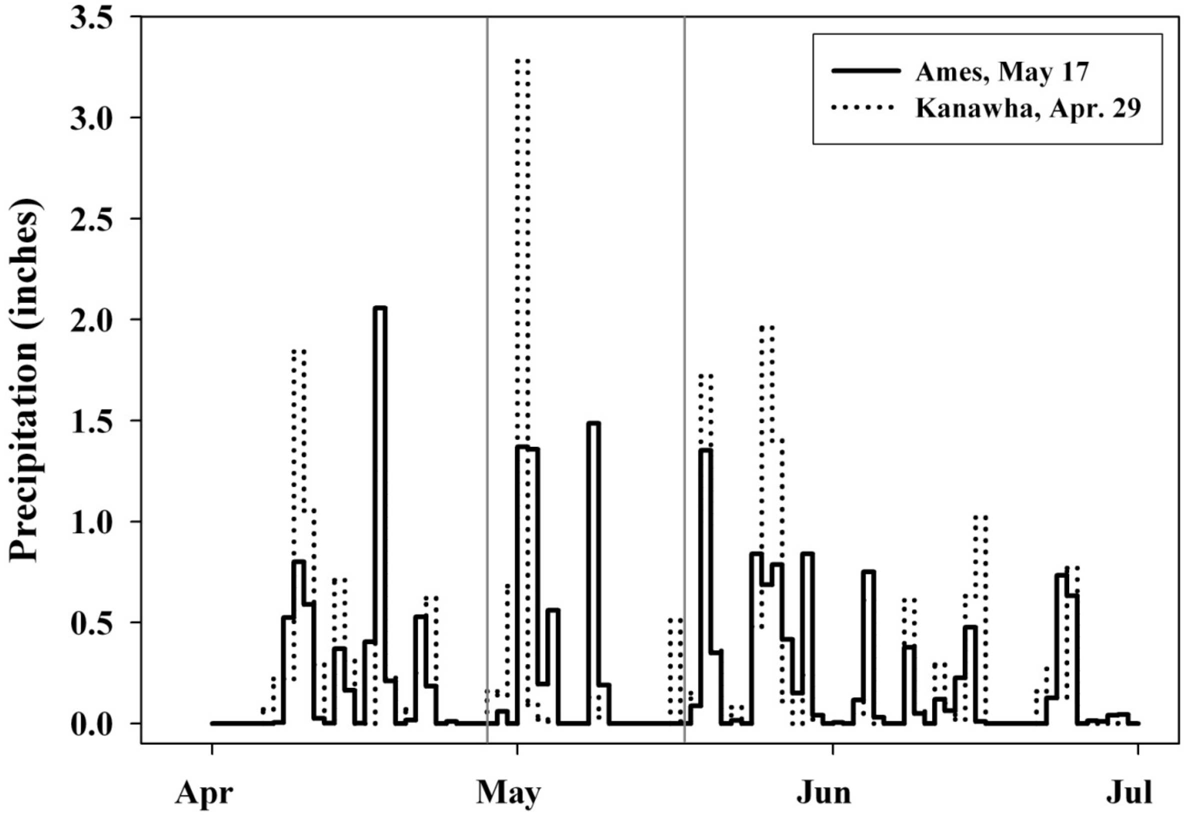

Figure 1. Precipitation in the early growing season and indicated treatment application dates at both research sites in 2013.

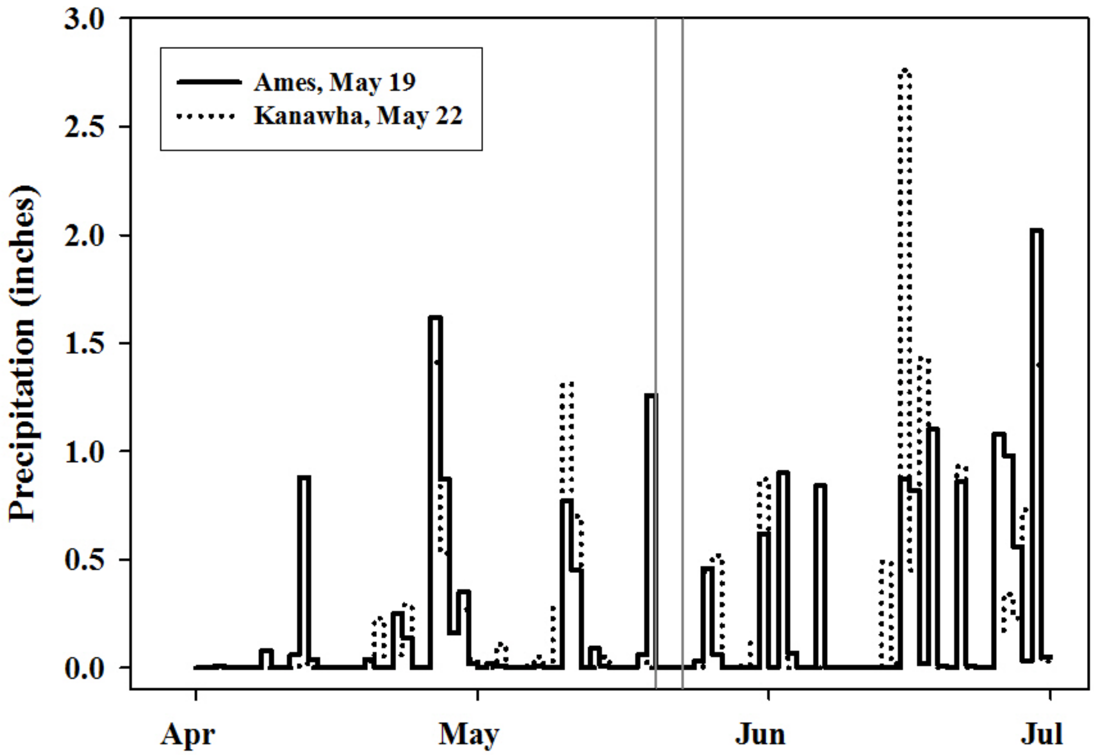

Figure 2. Precipitation in the early growing season and indicated treatment application dates at both research sites in 2014.

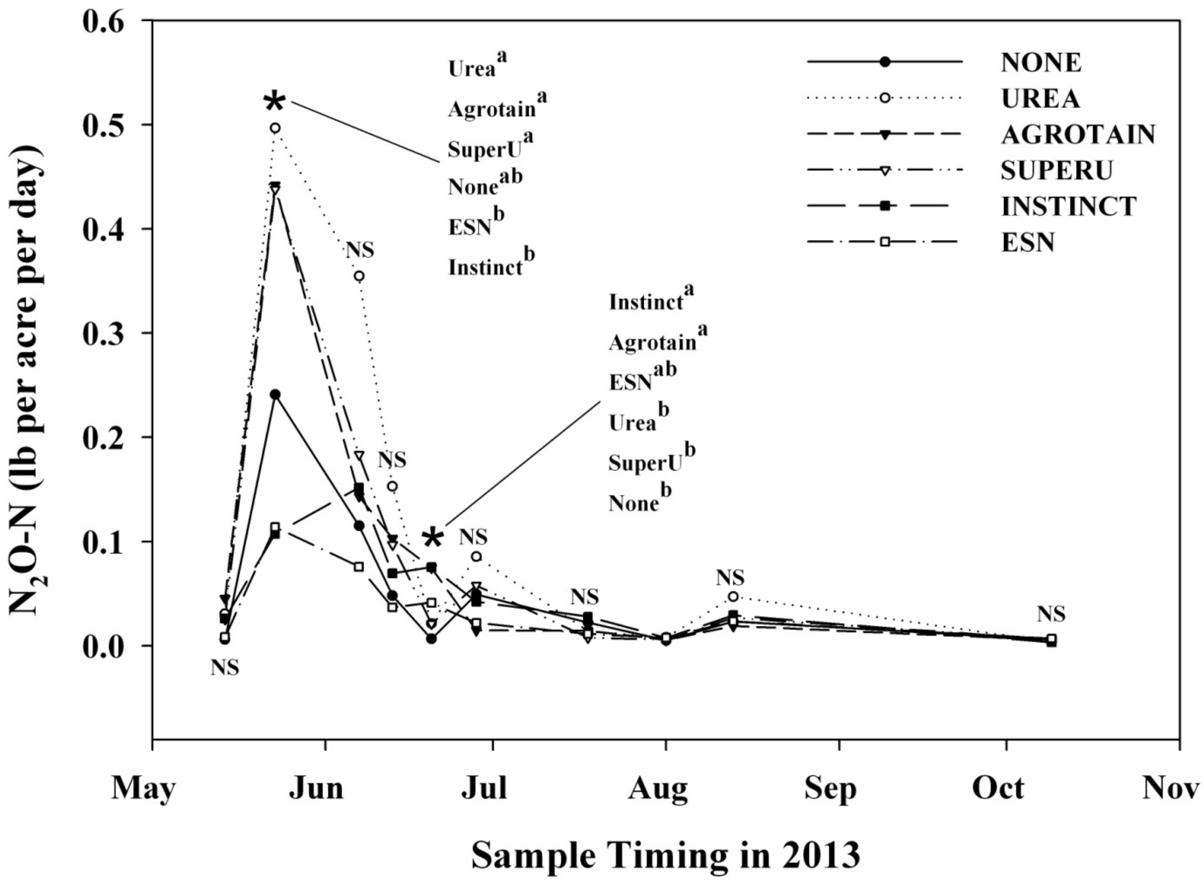

Figure 3. Nitrous oxide (N_2O-N) emission measurements collected from the soil (incorporated treatments) at Ames in 2013. Sample dates began on May 14 (just prior to N application) and ended on Oct. 9 (corn maturity). Treatment effects were analyzed by sample date (NS; not significant, *; significant). When treatment effect was significant, letters indicate statistical differences.